Critical Care

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The development of a non-contact tachycardia and tachypnea monitoring system, a clinical trial on shock patients

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Dear Editor,

Antimicrobial therapy and other treatments are strongly desired to reduce the mortality rate of patients in septic shock [1]. Joo Heung Yoon et al. reported a machine learning model-based method for predicting hypotensive events using physiological vital signs in the intensive care unit (ICU) [2]. In clinical settings including outside the ICU, such as a general ward or elderly care facility, blood pressure is not always measured frequently, and vital signs of shock are sometimes overlooked. To alert medical professionals of the possibility of shock by 24-h measuring shock-induced compensatory tachycardia and accompanying tachypnea, we developed a vital sign-based, non-contact, 24-h continuous monitoring system, which does not need any electrodes or blood pressure cuffs that burden patients. The proposed system uses dual 24 GHz Doppler radars beneath the bed mattress, each transmitting at a power (10 mW) comparable to wireless microphones [3, 4]. Previously, our research group proposed an infection screening method using Doppler radar-derived vital signs [5]. Using the same Doppler radar, the system described herein makes non-contact and 24-h measurements of tachycardia and tachypnea. We had difficulty making non-contact heart rate (HR) measurements in shock-induced patients because shock drastically decreased HR-related radar output signals. To solve this problem, we developed a novel method that uses a power spectrum density (PSD)-averaged signal for patients in shock (PASS).

The clinical study of the proposed system was conducted at Genkikai Yokohama Hospital, Nananosato elderly care facility, and Airanomori elderly care facility, using bedridden patients (3 males, 9 females, aged 52–91 y) with possible acute exacerbation. As a reference, systolic blood pressure (SBP) was measured using a blood pressure cuff, and HR was evaluated using a pulse oximeter on a fingertip.

Figure 1 shows a non-contact tachycardia and tachypnea monitoring system using dual compact Doppler radars located beneath bed mattresses (Fig. 1a) and the PASS to determine whether SBP is 90 mmHg or less (Fig. 1b–e). The radar output signal of a patient in septic shock and with SBP of 60 mmHg is shown in Fig. 1b. The PASS was derived from 512 averages of the PSD (Fig. 1e), which was obtained from the fast Fourier transform (FFT) of the radar output signal over a 60 s window shifting in 5 s steps. Even without using the PASS, the respiratory rate (RR) used for tachypnea evaluation could be derived from a PSD peak (in this case,

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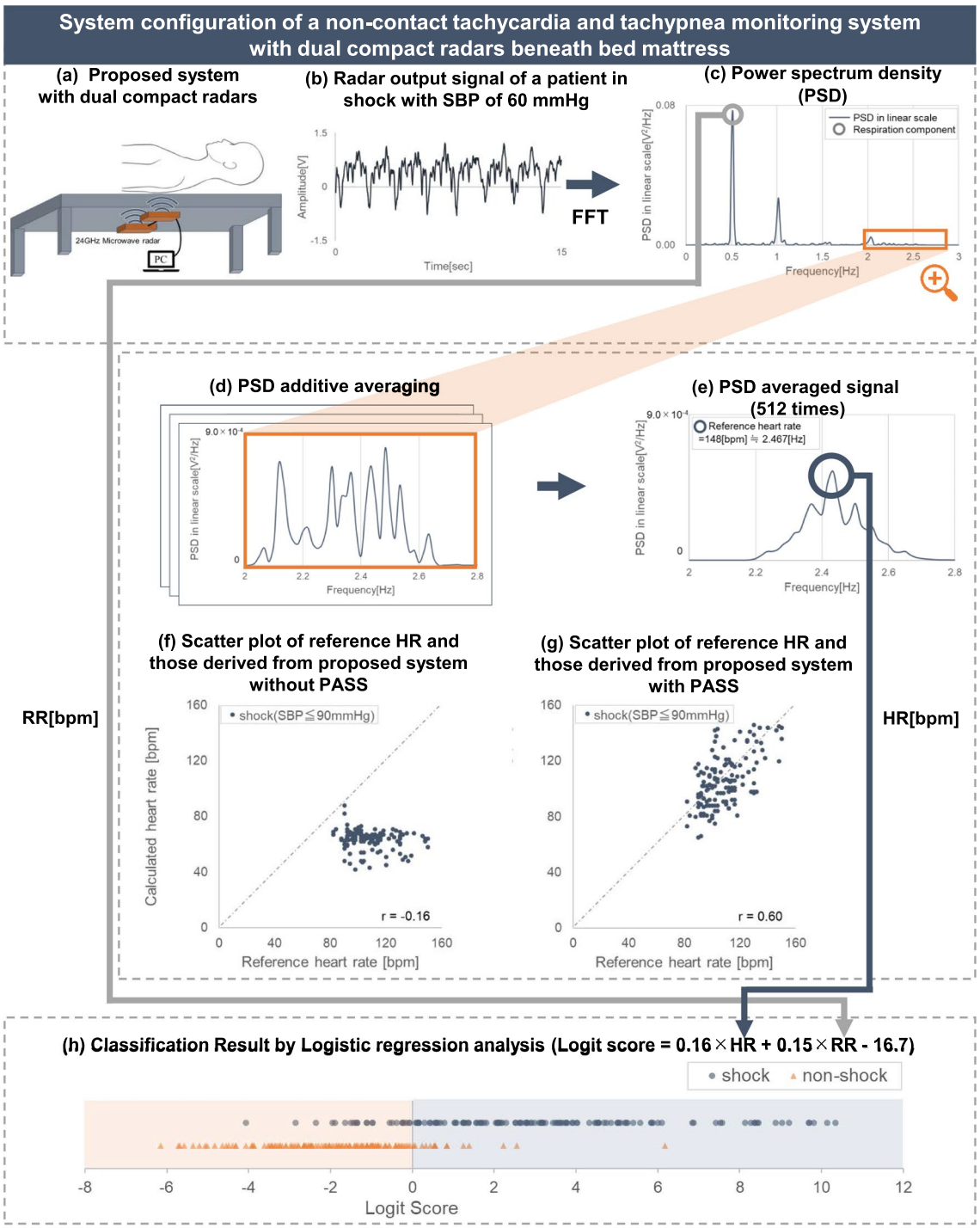
System configuration of a non-contact tachycardia and tachypnea monitoring system with dual compact radars beneath bed mattress
(a) Proposed system with dual compact radars
24GHz Microwave radar
PC
(b) Radar output signal of a patient in shock with SBP of 60 mmHg
Amplitude[V]
Time[sec]
FFT
(c) Power spectrum density (PSD)
PSD in linear scale
Respiration component
PSD in linear scale[V²/Hz]
Frequency[Hz]
(d) PSD additive averaging
(e) PSD averaged signal (512 times)
Reference heart rate =148[bpm] ≒ 2.467[Hz]
RR[bpm]
HR[bpm]
(f) Scatter plot of reference HR and those derived from proposed system without PASS
(g) Scatter plot of reference HR and those derived from proposed system with PASS
shock(SBP≦90mmHg)
Calculated heart rate [bpm]
Reference heart rate [bpm]
r = -0.16
r = 0.60
(h) Classification Result by Logistic regression analysis (Logit score = 0.16×HR + 0.15×RR - 16.7)
shock
non-shock
Logit Score

Fig. 1 **a** System configuration of a vital sign-based, non-contact system for continuously monitoring tachycardia and tachypnea. Dual compact radars beneath the bed mattress detect tachycardia from the power spectrum density (PSD)-an averaged signal for patients in shock (PASS). **b** Radar output signal (averaged 512 times) of a patient in shock with a systolic blood pressure (SBP) of 60 mmHg. **c** The PSD of the radar output signal revealed shock-induced tachypnea (respiratory rate (RR) = 30 breaths/min [0.5 Hz]). **d** Without PASS-based measurement, the heart rate (HR) at approximately 2.47 Hz was not observed. **e** The PASS-based measurement revealed shock-induced compensatory tachycardia (HR = 148 bpm [2.47 Hz]) and improved the correlation between the reference HR and the proposed system from **f** − 0.16 to **g** 0.60. **h** Using HR and RR as explanatory variables, logistic regression analysis separated shock from non-shock conditions with 83% sensitivity and 88% specificity (logit score ≥ 0, suspected shock; logit Score < 0, suspected non-shock)

0.5 Hz [30 breathes/min]) (Fig. 1c) because the respiratory PSD amplitude was much larger than the cardiac PSD amplitude. In addition to the 0.5 Hz respiratory frequency, the PSD of the radar output signal contained the second harmonic (1.0 Hz), but the heartbeat frequency component was not observed (Fig. 1c, d). In contrast, the PASS revealed a compensatory elevated HR at 2.47 Hz (148 bpm) after comb filtering to erase the high-frequency harmonics of the respiratory component (Fig. 1e). The correlation between the reference HR and that detected using the proposed system was improved from − 0.16 without PASS-based measurement to 0.60 with PASS-based measurement (Fig. 1f, g).

Two out of 12 examinees (an 80-year-old female and an 81-year-old male) developed shock with SBP < 90 mmHg. Of the 277 SBP measurements for 12 examinees, 139 had SBP ≤ 90 mmHg, and 138 had SBP > 90 mmHg. Logistic regression analysis was used to separate shock (SBP ≤ 90 mmHg) from non-shock (SBP > 90 mmHg) conditions with HR and RR as explanatory variables. The following logistic regression equation was derived:

$$\text{logit score} = 0.16\ \text{HR} + 0.15\ \text{RR} - 16.7.$$

A logit score ≥ 0 indicated suspected shock, and a logit score < 0 indicated no suspected shock (Fig. 1h). Five-fold cross-validation revealed 83% sensitivity and 89% specificity.

The proposed system has a limitation; the system has difficulty distinguishing tachycardia induced by shock from that caused by another reason. Nonetheless, we successfully made non-contact measurements of shock-induced tachycardia in a patient with an SBP of 60 mmHg with a greater sensitivity than that achieved by palpating the carotid artery; further investigation is needed.

In summary, to encourage medical professionals to test for shock when a logit score ≥ 0, the proposed PASS-based system appears promising for continuous monitoring of possible shock in locations outside the ICU, such as long-term care hospitals and facilities and in-home medical care environments. The studies involving human participants were reviewed and approved by the Ethics Committee of Genki Kai Yokohama Hospital Ethics. The patients provided their written informed consent to participate in this study.

Abbreviations

ICU	Intensive care unit
HR	Heart rate
PSD	Power spectrum density
PASS	Power spectrum density-averaged signal for patients in shock
SBP	Systolic blood pressure
FFT	Fast Fourier transform
RR	Respiratory rate

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AS, KH and TM wrote the manuscript. KH and YH supervised the medical aspects. TK, SS, and GS contributed the engineering aspects of the monitoring system. All authors read and approved the final version of the manuscript.

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Availability of data and materials
The datasets used and analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
The studies involving human participants were reviewed and approved by the Ethics Committee of the Genki Kai Yokohama Hospital Ethics. The patients provided their written informed consent to participate in this study.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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